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METHODS: SOFTWARE, REVIEWS, NOTICES

Structural Equation Modelling

*Jeremy Miles **

Abstract: Structural Equation Modelling (SEM) is a relatively recently developed statistical technique based upon factor analysis and multiple regression. This review will cover four of the most widely used (in psychology departments) packages, looking in particular at their suitability for use in a teaching environment, rather than an in depth look at their technical capabilities: LISREL 8.20, EQS 5.6, AMOS 3.6, SEPath. The four programs reviewed were all tested running Windows 95, on a 166 MHz Pentium, with 32 MB RAM.

Introduction

When using what might be termed "traditional" statistics data are explored, and relationships tested, to derive a model. When using SEM a model is hypothesised, and the ability of the model to have produced the data is tested. Most commonly the result of that test is a X^2 value, which gives a probability value for a test of equality between the data and the model. A non-significant value is usually sought, as this means that no significant difference exists between the data and the model, and the model is not therefore rejected.

Recently SEM has seen a surge in popularity in psychology both internationally, and in the UK (Tremblay and Gardner, 1996). This has arisen for two reasons, firstly due to recognition of the capabilities and advantages of using an SEM approach, secondly, and possibly more importantly is the availability of user friendly software. Alongside this increase in popularity is an increase in the number of psychology departments that are offering courses in

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SEM, or have SEM included in courses on statistical analysis, both at an undergraduate, and a postgraduate level.

LISREL 8.20

LISREL (Linear Structural Relationships), written by Joreskog and Sorbom, has been around for longer than most other SEM programs, and version 8.20 was released in January, 1998. LISREL is backed up with extensive documentation on Scientific Software's web pages.

Look and Feel

The latest version of LISREL (LISREL-Interactive) is a considerable change for anyone familiar with older versions of LISREL. LISREL comes with two programs, LISREL and PRELIS (PRE-Processor for LISREL). Prelis is used for screening data, and creating the appropriate correlation, covariance and weight matrices. Both LISREL and PRELIS have undergone considerable changes since their previous releases. This review will focus mainly on LISREL, as this is the program that students have the greater trouble learning, and spend longer actually using. In early versions, there was only one way to enter a LISREL model - using LISREL syntax. Even the greatest enthusiast of LISREL syntax would admit that it has a reasonably steep learning curve. The model is estimated by manipulating the elements of 8 matrices, each referred to with a Greek letter (Λ , Λ , Θ , Θ , Φ , Ψ , Γ and B), to estimate means two additional matrices are required (τ and κ). The LISREL language has two major advantages. Firstly, it is very parsimonious - a model can be written, and communicated, using very little syntax. It is also the most common language for books and technical articles to use.

More recently a second language was added to LISREL, called SIMPLIS (SIMple LISREL). This is a much simpler language, in which the individual equations are specified, rather than the matrix elements, much as in EQS. This language is much simpler for the beginner to learn, and is also featured in at least one book designed for those learning SEM (Schumacker and Lomax, 1996).

When carrying out analysis using previous versions of LISREL, the data were never seen, LISREL was told where the file that contains the data was to be found. This could be a problem for students, used to Windows based, spreadsheet-like statistics packages, who, when they asked "How do I open the data?" did not like the answer "You don't." This latest version of LISREL features a spreadsheet like window, which opens, and views the data.

This version of LISREL implements two new methods of model input. The project and the path diagram. Path diagram input is done via a drawing. Variables are dragged from the side bar, and paths drawn in between them. Additional aspects of the model are set up using menu commands. The path diagram input is shown in Figure 1 (all Figures are listed in the Appendix), the

bar on the left contains variables, which are dragged onto the diagram, the floating menu on the right contains paths, which are drawn onto the diagram. Project input is similar to the path diagram input, with the exception that the model is input using menus and dialog boxes. The student is taken through the steps in building a model, and prompted for the aspect of the model which is required. Figure 2 shows the dialog box for the addition of equality constraints. Both input types are much easier for the beginner to understand, and learn, than LISREL or SIMPLIS syntax (although it does take considerably longer to input a model). When a button is clicked the program produces the syntax from the project or path diagram, which can be in either LISREL or SIMPLIS, enabling the learner to gain an understanding of the syntax.

The output from LISREL consists of a text file, and a path diagram of the model, if requested. The path diagram is a very useful tool for examining the specification of the model. The diagram can focus on the X-model, Y-model, structural model, or the basic mode, and can feature the parameter estimates, T-values, modification indices, or expected changes. This simplifies the task of ploughing through the syntax and extracting the correct information, for the learner.

Features

Until recently LISREL was lagging behind some of the other SEM programs in terms of features. This latest version corrects this, and puts LISREL back among the front runners. It has features for dealing with ordinal data, including polychoric correlations (with up to 15 categories), asymptotic distribution free estimation (ADF) estimation (also sometimes referred to as weighted least squares, WLS), and procedures for calculating mean differences amongst from ordinal data (see Joreskog, 1997). LISREL produces a range of fit indices, including four types of chi-square (including the Satorra-Bentler scaled chi-square), and now estimates non-normal standard errors.

Overall

LISREL was still the most popular program for carrying out SEM, but was beginning to fall back, due to competition from other programs, which were more user friendly and featured more recent innovations. This version of LISREL increases the features, and has vast improvements to the user friendliness. Users of previous versions will be pleased to find out that the program seems to be much less likely to crash than previous versions of LISREL, although the time taken to do the calculations does seem to have increased.

EQS 5.6

EQS (pronounced "Ecks") is written by Peter Bentler, and is currently on version 5.6. (although a patch to upgrade to a beta version of 5.7 is available on the Multivariate Software Web pages).

Look and Feel

The look and feel of EQS is similar to that of LISREL. A model can be entered using syntax, a path diagram, or via a path diagram. The syntax for EQS is very similar to the SIMPLIS syntax for LISREL. Each parameter to be estimated in the model is individually specified, as an equation.

The menus take the user through the process of specifying the basic model, using point and click. More technical aspects, or modifications, such as equality constraints can then be added using further menu options. By using the menus the syntax is built up, in a very similar way to LISREL. Figure 3 shows the dialog box used to add inequality constraints in EQS.

The path diagram builder works in a similar way to the menus. The basic model is produced, and then modifications are made via the menus. This writes a syntax file in much the same way as when the path diagram is built from the menus. The diagram drawing part of the package is shown in Figure 4. The toolbar on the left of Figure 4 is used to add features to the diagram, by clicking on a tool and then clicking on the diagram.

Output is produced in the form of a text file, and can be exported to the diagram, to show parameter estimates on the path diagram.

While the structure of the path diagram input and output, and the structure of the syntax files make EQS very user friendly, the EQS interface is slightly unusual. The help files are not standard Windows help files, but run using the help viewer supplied with EQS. Although this presents no problem when one has become used to it, it is a little disconcerting to find the help file not behaving as one expects. The actual calculations are carried out in a DOS window, which opens when a file is run. The DOS window must then be closed, and the file it has produced opened in EQS.

Features

Unlike other SEM packages, EQS is also capable of producing a range of other analyses (t-tests, ANOVA, factor analysis) and graphs to represent the data, this is useful, as it means that the package feels much more like a statistics package that people are used to dealing with.

EQS features a range of procedures for dealing with ordinal and skewed data, including polychoric and polyserial correlation, ADF estimation and Satorra-Bentler scaled X^2 (which it refers to as robust).

Overall

The latest version of EQS is a powerful, and user-friendly package, sufficiently straightforward for beginners. The latest version seems to have overcome the stability problems that beset previous versions, I could not make this program crash.

AMOS 3.6

AMOS (Analysis of MOment Structures, written by Jim Arbuckle, is a relative newcomer to the SEM software scene. A student version is available, for free, from the SmallWaters WWW site. AMOS is also available as an additional module within SPSS for Windows.

Look and Feel

The data in AMOS are entered either as a separate text file, or, if the program is being used with SPSS, the data are taken directly from SPSS, incorporating their variable names.

A model is entered in AMOS using either a path diagram, or syntax. The two sources of input are not linked in the same way as in LISREL and EQS - the path diagram does not write the syntax, it is the path diagram that functions as the syntax.

The path diagram drawing part of the program is the slickest of all the packages reviewed here, and is shown in Figure 5. The toolbar on the left hand side of the diagram is used to draw parts of the diagram. Icons on the buttons are fairly intuitive, and a description of the button appears in the title bar, when the mouse is held over the button. The lorry icon is used to move a part of the diagram, the rubber on the end of the pencil to erase, and the abacus to calculate.

Additional commands are entered using what AMOS calls \$ commands. These appear in a separate window, which is accessed via a toolbar in the drawing program. Figure 6 shows the \$ command entering dialog box. The listing on the right contains all of the possible \$ commands, and the window on the left contains those that have been selected. Double clicking an option in the list of string commands moved it to the window on the left. If a parameter is required (as in Iterations), an additional dialog box appears, requesting the required value. If a user is sufficiently familiar, the \$ commands can be typed in, to increase the speed.

Given the refinement of the input parts of the program, the output is a slight disappointment. This is not to say that it is any worse than EQS or LISREL, but merely no better. A text file is produced and displayed in a text window, much the same as in the other packages.

Features

AMOS does not have some of the procedures for handling ordinal data that LISREL and EQS do have. The supporting documentation states (very truthfully) that the procedures available in LISREL and EQS are problematic unless large samples are used. The AMOS WWW pages state that a future release of AMOS will incorporate a technique for dealing with ordered categorical data, and should be out in late 1998.

AMOS has two features to make it stand out from other programs. The first feature is its bootstrapping capabilities. It automatically calculates bootstrap

confidence intervals, and bias-corrected intervals, these can be parametric or non-parametric. In addition, Bollen and Stine (1993) have showed that the %² estimates derived when bootstrapping is used are biased, and proposed a correction to this. AMOS is the only program to incorporate this correction.

The second feature in AMOS is its handling of missing data. AMOS incorporates a Full Information Maximum Likelihood (FIML) estimation algorithm, for the analysis of missing data. This uses all of the information available, and provides unbiased parameter estimates.

Overall

AMOS is a slick, smooth program to use, with an intuitive and user friendly feel. It is a program that feels like it was designed to be used for teaching, and for people who are not necessarily knowledgeable in SEM techniques.

SEPath

SEPath is written by James Steiger, and available as part of the Statistica package, produced by StatSoft.

Look and Feel

The look and feel of SEPath is of a very smooth windows program. The program is part of a full statistics package (Statistica 6.0) which makes it feel familiar to people who are used to using something like SPSS.

SEPath is the only package reviewed here which does not have a path diagram input function, the model is entered via syntax, or built via dialog boxes. The dialog boxes work so well that they are not really missed. Rather than having a sequence which must be followed to build a model, the dialogs are all accessed from one "Start-up Panel," and can be accessed in any order. One very useful feature, which is true of all the programs that make up the Statistica package, is that an OK button is never "greyed out." It is always possible to press OK, and if something has not been done, a warning will appear informing the user what needs to be done. This avoids the mysterious feeling one can get when you don't know what you haven't done, but you know the program needs some additional input.

One of the input dialog boxes is shown in Figure 7, the path construction tool. The user selects two variables from the two boxes on the left, the type of path, from the radio buttons, and presses the add button to add the path to list on the right.

The dialog boxes write syntax which is then run, but the syntax can be run directly from the "master" dialog box, without the user ever knowing that the syntax exists.

The output from SEPath puts all of the other programs to shame. The other programs drop the results into one long text file, which is then "dead." Using one of the other packages reviewed here, if you find that you want some aspect

of output, but did not request it, the analysis must be re-run. This leads to a tendency to ask for everything you might want in the output, much of which turns out to be redundant. SEPath organises its output in much the same way that its input is organised. There is one central "master" control dialog, from which different parts of the output are requested. These are then displayed in dialog boxes. Figure 8 shows the main dialog box for the output, the buttons access additional output. (Some of the buttons are greyed out, because a covariance matrix was used as input, rather than raw data.)

Features

Like AMOS, SEPath does not calculate polychoric/polyserial correlations for ordered categorical data. Unlike all the other programs reviewed here SEPath also does not calculate modification indices (or any similar index, such as the Wald tests, given by EQS), however this is a deliberate decision to leave them out, as they are often abused (and it can be argued that they have no legitimate use).

The main feature that makes SEPath stand out is in its calculation of standard errors when correlation matrices are analysed. Classical SEM statistical theory is based on the distributional properties of the elements of a covariance matrix. Unfortunately, covariance and correlation matrices have different distributional properties, so if you use theory based on a covariance matrix to analyse a correlation matrix, you can have problems (Cudeck, 1989). One can get around this by analysing covariance matrices, but if a covariance matrix is not available (such as when re-analysing published data - a useful learning experience), this is not possible. It is possible to get around this by "tweaking" the program, with some clever syntax, using non-linear equality constraints in LISREL or EQS, but it is not easy for the beginner. SEPath provides correct standard errors by default.

Overall

SEPath lacks some of the features of some of the other programs, but if these features are not needed by everyone, and so will probably not be missed. The fact that its input system is easy to use interface, and the fact that its output is second to none, make this a good choice for beginners,

Concluding Remarks

This generation of SEM programs represent a move from the sidelines of psychological research and analysis onto the mainstream. A few years ago SEM programs were obscure, difficult to use, hard to learn and (not surprisingly) rarely used. SEM programs tend to be written by and associated with, a single author, and the program reflects the interests, and prejudices, of that author. This is still the case, each program excels in one aspect. LISREL in

the analysis of mean structures with ordinal data, EQS in the analysis of non-normal data, AMOS in missing data and bootstrapping, and SEPath in standard errors (and its lack of modification indices).

Any of the programs here could be recommended for use in either a teaching or a research environment. They can all import a range of file types (including SPSS files), they all have similar features and all are fairly simple to use (given that SEM has a fairly steep initial learning curve at the best of times).

One thing which does divide the programs are the number of books about them, and their use in published research. It seems from my very brief survey of the literature that most theoretical articles referring to SEM use LISREL specification and syntax. While this is not difficult to learn, if you understand the principles of SEM, it represents an additional step. Most introductory texts also use LISREL as an example, although EQS is catching up. A quick check in the Internet Bookshop (<http://www.bookshop.co.uk>) revealed 8 books with LISREL in the title, 3 with EQS in the title, and none for either AMOS or SEPath.

This review has necessarily only covered a small number of programs that are available for SEM, a very good source of information for other programs that are available is the SEMNET FAQ, maintained by Ed Rigdon, at Georgia State University, and available at <http://www.gsu.edu/urmkteer/semfaq.html>.

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Program	Authors	Hardware	Content	Present ation	Publisher	WWW Page	Cost
LISREL	K. Jöreskog and D Sörbom	Win 3.x/95	*****	****	Scientific Software International, Chicago, USA.	www.ssicentral.com	\$575 ²
EQS	P Bentler	Win 3.x/95/Mac	*****	****	Multivariate Software, Inc.,	www.mvsoft.com	\$595 ²
AMOS	J Arbuckle	Win 3.x/95	****	*****	Smallwaters, Inc., Chicago.	www.smallwaters.com	\$465 ³ / \$325 ⁴
SEPath ¹	J Steiger	Win 3.x/95	****	*****	StatSoft (UK) Ltd., London	www.statsoft.com	£795 ^{2, 5}

Notes
¹Unavailable as single package, comes as part of Statistica package.
²Single user commercial license price. Academic discount / network licenses may be available.
³Single user commercial license.
⁴Single user academic license. Network licenses available. Also available from SPSS UK Ltd. This option will be cheaper if university already has an SPSS license.
⁵This price is for the Statistica pace.

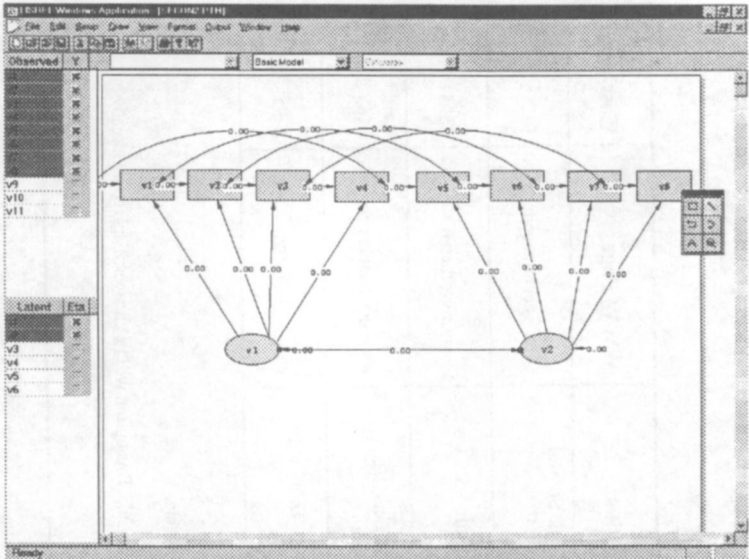


Figure 1: LISREL – Interactive path diagram input

The 'Constraints' dialog box in Project input shows the following constraints: EQ TD(3,3) TD(5,5) TD(4,4). The 'Groups' dropdown is set to 1. The 'Parameter' list includes Lamda-X, Phi, and Theta-Delta. The 'Free' list includes PH(1,1), PH(2,1), and PH(2,2). The 'EQ' button is selected. The 'OK', 'Cancel', 'Next', and 'Help' buttons are on the right. A numeric keypad is at the bottom right.

Figure 2: Addition of equality constraints in Project input

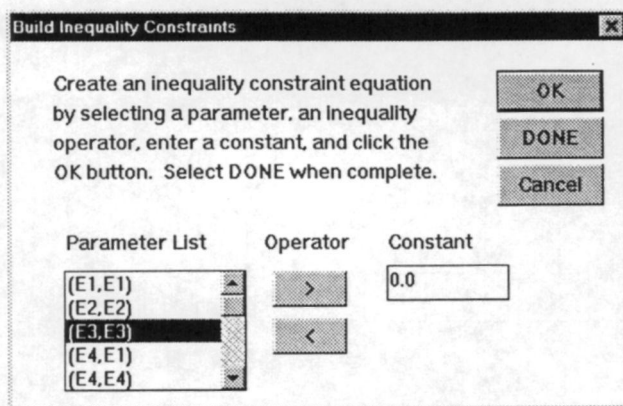


Figure 3: Dialog box to create inequality constraints in EQS

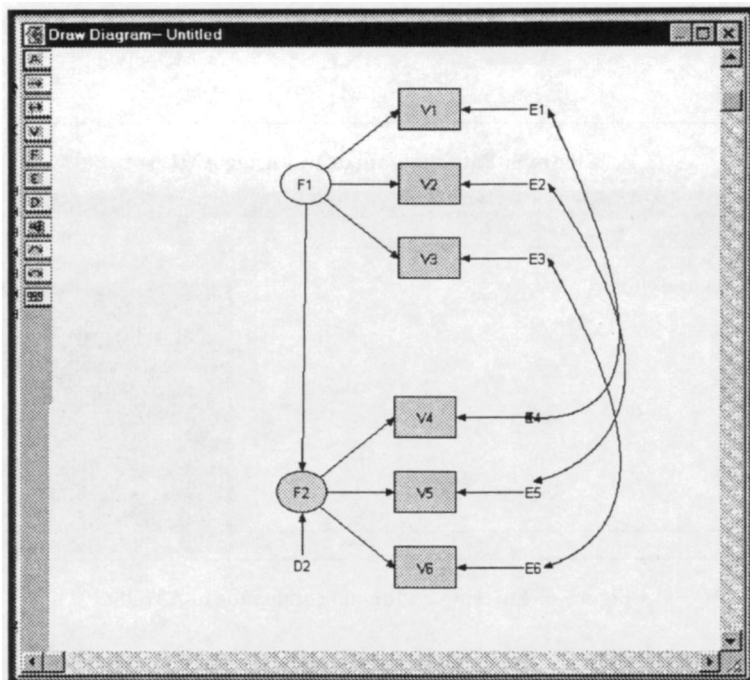


Figure 4: Diagrammer in EQS, used for producing path diagrams

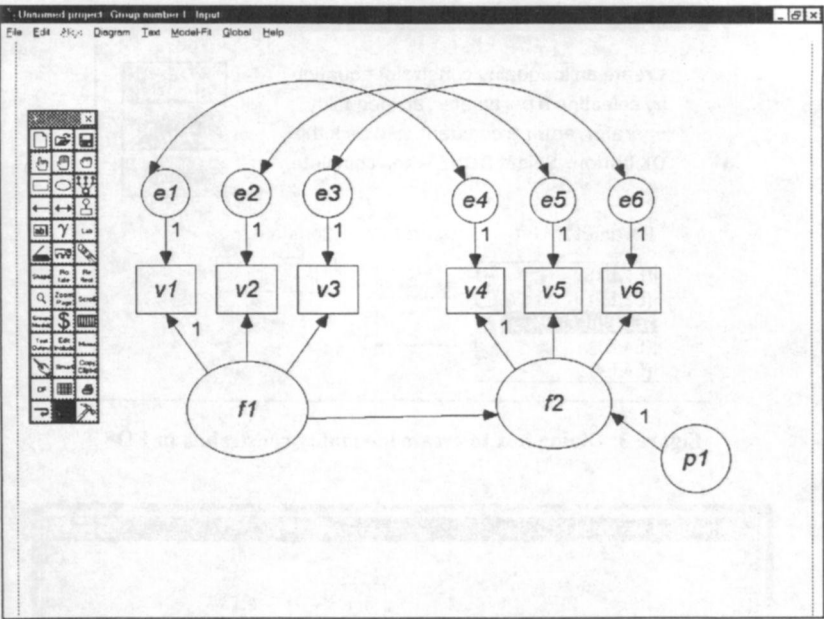


Figure 5: Path diagram drawn using AMOS

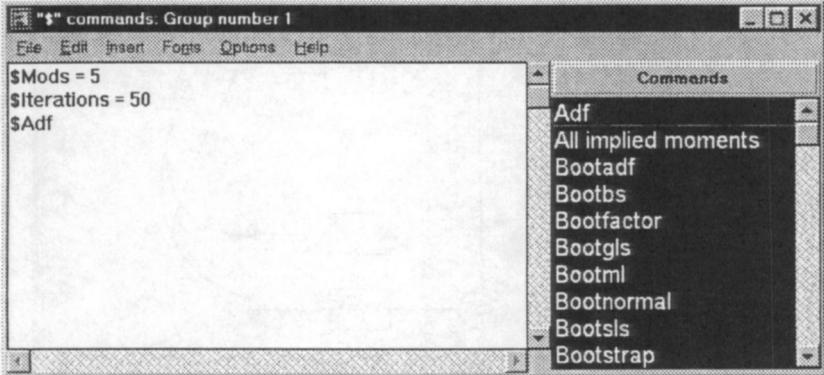


Figure 6: Entering additional commands in AMOS

Path Construction Tool

Variables

From: **Manifest** To: **Latent**

VIS_PERC
CUBES
LOZENGES
PAR_COMP
SEN_COMP
WRD_MNG
ADDITION
CNT_DOT
ST_CURVE

Factor1
Factor2
error1
error2
error3
error4
error5
error6
error7
error8
error9

Path Type

☒ X→Y
☐ X-Y
☐ Residual
☐ Correl.
☐ Covar.

Add >>

☒ Edit Latent

Paths

(Factor2)-8→[WRD_MNG]
(Factor2)-9→[ADDITION]
(Factor2)-10→[CNT_DOT]
(Factor2)-11→[ST_CURVE]

(error1)→[VIS_PERC]
(error1)→[CUBES]
(error1)→[LOZENGES]
(error1)→[PAR_COMP]
(error1)→[SEN_COMP]
(error1)→[WRD_MNG]
(error1)→[ADDITION]
(error1)→[CNT_DOT]

Parameters

☒ Include ☒ Increment

Par. #: **21** **Renumber**

Start Value

☐ Include Value: **5**

Residual Var

Base Name: **EPS** Base Number: **1**

Group **Endgroup** **Comment**

To specify Paths

1. Select Arrow (X→Y) or Wire (X-Y)
2. Select variables in the From list
3. Select variables in the To list
4. Click Add.

To specify Correlations, Covariances, or Residuals:

1. Set path type to Cov. Corr., or Residual
2. Select variables in To list
3. Click Add

To remove Paths. Highlight and click Cut.
For more information press F1.

OK **Cancel** **Parameters**

Figure 7: Path construction tool from SEPath

Structural Equation Modeling Results

Method of Estimation: ML
Discrepancy Function: 2.65
Maximum Residual Cosine: 0.000734
Max. Abs. Gradient: 0.00102
Max. Abs. Constraint: 3.12E-006
ICSF Criterion: 2.19E-005
ICF Criterion: 0.00047
Boundary Conditions: 0

Chi-Square Statistic: 188.423
Degrees of Freedom: 27
Chi-Square p-level: 0.000000
Steiger-Lind RMSEA
--->Point Estimate: 0.276
-->Lower 90% Bound: 0.238
-->Upper 90% Bound: 0.316
RMS Stand. Residual: 0.263

Goodness-of-Fit Indices

☒ Noncentrality-Based Indices
☒ Other Single Sample Indices
☒ LeGrange Multiplier Statistics

Tests of Assumptions

☒ Univariate Skewness ☒ Multivariate Kurt
☒ Univariate Kurtosis ☒ Reflector Matrix

Iteration History

Model Summary **Cancel**

Basic Summary Statistics

Analysis of Residuals

☒ Standardized Residuals
☒ Normalized Residuals
☒ Normal Probability Plot
☒ Input Matrix
☒ Reproduced Matrix

Figure 8: Main Dialog Box for Output of SEPath